

Recommendations for a Commercial Vehicle to Roadway Communications National Standard

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Background and Summary

This is the final report by the Lawrence Livermore National Laboratory (LLNL). Based on our studies of the Electronic Toll and Traffic Management (ETTM) industry we make recommendations for a possible future national standard for short range Vehicle-to-Roadway Communications (VRC) for Commercial Vehicle Operations (CVO).

Of primary interest to the Federal Highway Administration, our sponsor, are Mainline Automated Clearance Systems (MACS). In such a system, CVs would exchange data with weigh-stations and ports of entry at highway speeds using wireless Radio Frequency (RF) techniques to enable automated clearance. The CV would carry a transponder (or tag) and transmit electronic credentials, safety data, in-transit data, etc. on command from a roadside transceiver (or reader) upstream from the weigh-station or port of entry. Computer processing of this data, plus the weigh-in-motion reading and historical information, would be used to decide whether to direct the truck to stop for manual clearance or proceed.

In 1993 LLNL and NIST completed studies of the MACS user requirements and vendor ETTM hardware systems and communications protocols. In those reports we were constrained to consider only possible standards supported by existing hardware. This report benefits from the freedom to recommend the best approach based on our analysis, more recent developments in this rapidly developing technology, more informed user input, other standard setting activities, and Federal Communications Commission (FCC) inclinations. Other standard setting organizations working on VRC include IVHS America's ETTM Steering Committee, the American Society of Testing and Materials (ASTM), the International Standards Organization (ISO) and Comite Europeen de Normalisation (CEN). We recommend good features found in vendor systems as well as some not yet realized. The result can be a non-proprietary standard employing best practice as well as industry acceptance.

In the recommendations section of this report we discuss the issues in detail. In this background and summary section we highlight our major recommendations:

- 1) The future operating frequency of ETTM systems should be 5.8 GHz; with 915 MHz serving at least the near-term. The FCC should be petitioned to give VRC applications primary status in the 5.8 GHz ISM band and continued use of the 915 MHz ISM band. System performance, cost, interference and FCC regulations are factors in selecting the operational frequency as discussed in section I (Frequency of Operation);
- 2) A flexible and efficient communications protocol similar to High-level Data Link Control (HDLC) should be selected. Multiple VRC applications are well served

using such a protocol which is well supported using a low-cost on-tag microprocessor. In section II (Protocols) we discuss the merits of flexible protocols featuring command codes, standards activities incorporating this feature, and multiple vendor adoption;

- 3) Tags should be programmable to handle new applications and user requirements with software rather than hardware changes to the tag. This is discussed in Section III (Programmable Tags);
- 4) Both active and backscatter tags should be supported in a national CVO standard; a similar conclusion to IVHS America's Steering Committee requirement for dual-mode readers or tags. This is discussed in Section IV (Uplink Signaling);
- 5) Lane or position determination must be achieved by the CVO VRC system. Weigh-in-motion readings must be associated with a particular vehicle, therefore the system must know the lane and position of the tag it is communicating with. Section V (Lane/Position Determination) discusses this issue;
- 6) Password and encryption strategies should be employed to assure the integrity of agency written data on the tag and the confidentiality of messages transmitted over-the-air. Section VI (Data Security) discusses this issue; and,
- 7) Other recommendations include a minimum tag memory for 2 kb (kilobits) of data, tags should have an interface to permit connection to an on-board computer, the communications rate should be 500 kbps (kilobits per second), and tags should sense and report their battery's condition. These are discussed in Section VII (Miscellaneous Recommendations).

Recommendations

I. Frequency of Operation

The choice of operating frequency involves a tradeoff between a number of technical and non-technical factors. System performance, cost, potential RF interference, and compatibility with Europe are the more important of these.

The Instrumentation, Scientific and Medical (ISM) bands centered at 915 MHz, 2.45 and 5.8 GHz are the most promising operating frequencies based on current and possible future FCC regulations. The need for additional spectrum for wireless communications makes these bands attractive to many users. The potential for interference grows with the number of devices and applications. While 915 MHz is the current operating frequency for most US ETTM deployments, the FCC would not grant primary or co-primary status to this application. Such status would offer protection from other licensed fixed-based users near an ETTM site. However, even with preferred status ISM, FCC Part 15, ham operators and mobile devices could still pose interference problems. Currently, agencies are applying for site licenses for ETC systems in the 2.45 GHz band, and IVHS America is poised to request primary status in the 5.8 GHz band. Current consensus on what the FCC may do dictates that 5.8 GHz is the best choice for the future; with 915 MHz best for the near-term and possibly wide-area IVHS applications. Going to 2.45 GHz for the near-term does not seem warranted; it also is becoming a busy band and favorable status from FCC appears doubtful.

Congress has mandated that the government give up claim to some of its spectrum. Plans call for this to happen over the next several years. The FCC is scheduled to reallocate the ranges 2390-2400 and 2402-2417 MHz next year. These bands would also be useful for ETTM applications given the right status. However, the FCC is only now soliciting comments on how to use these bands and have been deliberate in making such decisions. The uncertainty of the FCC ruling and incompatibility with Europe make this a dubious long-term strategy for ETTM.

A lower operating frequency may permit longer range communications which may be especially useful for wide-area IVHS applications. The signal strength captured by a receiver is proportional to its antenna cross-sectional area. This area is inversely proportional to frequency-squared ($1/f^2$) for antennas with the same directionality (gain). For example, the downlink received signals at 2.45 and 5.8 GHz would be 9 dB (7 times) and 16 dB (40 times) lower respectively than at 915 MHz using antennas with the same Field-of-View (FOV). For the uplink signals one obtains the same signal reductions for active tags, but from backscatter type tags one would receive 18 dB and 32 dB reductions at 2.45 and 5.8 GHz respectively since both tag and reader antenna cross-section areas enter its uplink signal equation. The use of an on-tag amplifier could compensate for much of this signal reduction at high frequency but with some added cost and circuit complexity.

Cost is another factor which may affect the choice of operating frequency. Cost of tags is a very important consideration for most applications. Here again, the lower frequencies are better. Very inexpensive components are currently available at 915 MHz and 2.45 GHz but not at 5.8 GHz. At 5.8 GHz RF circuit components (oscillators, modulators, receivers) are fabricated from GaAs which is a less well developed material than silicon. Cost estimates from vendors and other sources range to 100% increase in the initial cost of ETTM tags in going from 915 MHz to 5.8 GHz. The costs of these components should

decline when the market for 5.8 GHz ETTM devices becomes substantial but would not reach the levels obtainable with silicon devices.

RF Interference from nearby in-band transmitters is another important operating frequency consideration. Obtaining a clear channel from the FCC for ETTM operation at 5.8 GHz appears attractive in this regard. There are other users of the bands at 915 MHz and 2.45 GHz which could potentially interfere with ETTM operations at some sites. To date three site problems at 915 MHz has been brought to our attention. One occurred in Dallas where Amtech agreed to move to a different frequency in order to avoid interfering with another user of the band. They were able to move because their backscatter type tags permit frequency agility since the reader controls both uplink and downlink frequencies. In addition, ship radar was seen to interfere in early ETC experiments on the Coronado bridge in San Diego, and an intermittent source was detected near an air force base in California. Less data is available for 2.45 GHz but one vendor reports considerable activity in this band in the Los Angeles area with potential interference.

To date, active type tags have been designed with fixed uplink frequency; they don't offer frequency agility. Although the potential for interference exists, active tag vendors have not had interference problems and believe they can co-exist in the 915 MHz band. Some points support their view. First, interference with the downlink signals should be minimal since tags use narrow band filters and a simple diode receiver which requires high RF field strength at the tag ($\sim 0.1 \mu\text{W}/\text{cm}^2$) which should exceed the levels from most interfering sources. For example, an omni-directional interfering source as close as 100 m from the tag would have to transmit 100 Watts to equal this power density. Such high power sources so close to an ETTM site should be rare. On the other hand, the uplink RF signals are much lower in power. Fortunately, however, the reader antenna typically has a narrow FOV (~ 20 degrees) aimed at the road. Therefore, interference should be limited to on-vehicle devices as they pass through the communication zone and high power transmitters nearby not in the FOV. Signals from the later are received via scattering from the zone and coupling into the reader antenna's side lobes. In addition, the bit rate and signal modulation scheme of the interfering source would likely be significantly different from the ETTM system and so it's potential for interference reduced. Still, if a licensed fixed-base operator interferes at an ETC site there may not be a remedy without frequency agility.

Frequency agility could be added to active tags as a feature in at least two ways. Firstly, the reader could transmit to the tag a continuous wave (cw) RF signal at the desired frequency which the tag would "mimic". Or, secondly, the reader could transmit a message to the tag indicating the frequency the tag should employ at this site. In each case, additional circuit components would be required on the tag with unknown additional cost. This option should be investigated by the vendors.

We recognize, therefore, that future in-band interference possibilities may or may not pose a serious threat. If interference in the 915 MHz band becomes a problem, lack of primary status in the band may dictate the need for frequency agile tags.

In order to operate VRC systems at a common frequency in all countries, Europe plans to migrate over a ten year period to 5.8 GHz. This makes considering this frequency rather important as compatibility with Europe may be desirable. Cargo containers could then use one frequency for their tags instead of requiring dual-frequency operation (assuming that cargo containers will go to 5.8 GHz in Europe). Also, by choosing the same

frequency, the 5.8 GHz component market would be larger leading to a more rapid cost reduction.

Based on the above considerations (systems performance, cost, interference, compatibility) we recommend that 915 MHz be the operating frequency for the CVO MACS Application in the near term, and that the FCC should be petitioned for primary status for ETTM at 5.8 GHz to protect IVHS user services from future interference.

Furthermore, if IVHS America acquires a frequency allocation from the FCC for VRC at 5.8 GHz, the 915 MHz band should not be given up. This would permit differing CVO applications to use what's best in each situation. Considering the various technical issues, operation in the 915 MHz band is currently satisfactory, and should be acceptable in the future. Although not completely protected from potential interference, this band provides a good compromise of data rate, range, cost, maturity of technology and use of existing investments.

II. Protocol

The communication protocol specifies the format to be used by the reader and tag in transmitting data back and forth. It provides a means for the receiver to interpret the bit streams sent by the other's transmitter. Within the field of communications, there are many protocol choices, including some adopted by VRC vendors, which could satisfy the MACS and other CVO requirements. Flexibility to handle multiple applications and acceptance by the industry are two important factors in selecting a protocol.

VRC equipment can be used for MACS, toll collection, traffic management and many other applications. Market penetration for these devices may best be served using a flexible protocol scheme which can accommodate present and possible future applications using the same tag. No one can anticipate the extent and form of future VRC communication requirements, and therefore, protocol flexibility and tag reprogramming after manufacture capabilities should be of great benefit. Flexibility should permit one to tailor the communications to fit the application in an efficient and reliable manner. Current VRC vendor protocols can be classified as fixed, limited option set, and flexible, with a trend toward the latter.

The flexible ones (four of six US vendors evaluated) use protocols which are similar to HDLC. HDLC is a communications industry standard for hard-wired networks including a master module and up to 256 secondary modules all communicating on a common digital bus. HDLC is a bit oriented, synchronous transmission scheme wherein frames consist of the following bit fields: header, address, control, data, and cyclic redundancy code (CRC). The header permits the receiver to synchronize on the transmitter's bit period and start of message. Address is the ID number of the secondary module the master module is communicating with, control is a code which defines the remaining bit fields and their functions, data is the information being transferred, and CRC is a code which allows the receiver to detect errors in the bit stream.

The control (or command) code is the key to flexible and efficient communications. For the future we anticipate the need to extend or replace earlier protocols perhaps to cover new CVO services. Using a new command code, one can modify the message fields and their functions. Tags with microprocessors could be reprogrammed rather than replaced to handle the new messages.

In vehicle-to-roadway communications, we must deal with the fact that the identification numbers of the tags are not known initially to the reader and their presence in the communications zone is very transient. This requires some modifications to the HDLC protocol. Vendors handle the initial lack of ID number in one of two ways: (1) the communication zone FOV is limited to a single vehicle/single lane so that only one tag can respond to a request for ID control message (direct access), or, (2) the tags in a wide FOV communication zone are asked to respond in a randomly selected time slot from among several slots (Time Division Multiple Access (TDMA)). Once the ID is known, the reader can then talk to an individual tag using the address field. In this way both wide-area and limited FOV applications are supported by the flexible protocol. We anticipate that both wide-area and limited FOV deployments will be used and should be supported by the standard.

Both of these tag ID acquisition schemes are accommodated in the draft standard put forward by the ETTM Steering Committee which has the goal of establishing future interoperability between VRC systems throughout North America with one tag being able to communicate with different agencies anywhere the vehicle travels. Their proposed protocol is a modified version of HDLC.

We endorse the style of protocol in the ETTM Steering Committee proposed standard for the MACS application as it permits the desired flexibility and industry acceptance. Since Europe (CEN) is also believed to be developing a modified HDLC protocol, we believe that future tags could accommodate both locations even with some differences in the two protocol versions.

ASTM is also coordinating an effort to establish a national VRC protocol standard. Recently a subcommittee of vendors and users, on a split vote, passed up to committee a draft standard for public comment. Rather than an industry consensus, the draft standard permits three existing standards to co-exist on a time-shared basis. The reader would be required to support three types of tags. The strength of this approach is the support of existing tags and their protocols. Flexibility with respect to new protocols not among the initial three, is a significant weakness, as is the bandwidth inefficiency of the approach. We do not recommend this approach for the future because of its limited ability to incorporate additional protocols.

III. Programmable Tags

Most vendors are designing their current tags with inexpensive programmable digital controllers (microprocessors). This permits the support of flexible protocols and multiple applications. And, equally important, tags can accommodate new applications and protocols with firmware changes rather than hardware changes. These tags could be re-programmed to handle new uses as its owner chooses to add them. An additional advantage of an on-tag microprocessor is the ability to offer programmable digital interfaces to other on-vehicle devices. The same tag hardware can be easily configured to match the system requirement.

One potential disadvantage of the on-tag micro controller versus a dedicated state machine (hardwired logic which must be redesigned for message or protocol changes) is a longer signal processing time. The state machine can respond faster but at the expense of being inflexible. However, the reaction time of the microprocessor to a reader message is well tolerated by the system at the proposed bit rate and expected message lengths.

IV. Uplink Signaling

Two uplink signaling techniques are being employed by VRC vendors; active and backscatter. Active type tags employ an RF source and modulator on the tag to generate the uplink RF signals. Backscatter tags reflect a portion of incident cw RF energy from the reader by modulating the tag's antenna load impedance (which modulates the antenna's scatter cross-section).

Both hardware approaches can be successfully used for the various VRC applications. Each has some advantages, and both have strong proponents. To choose one over the other, while minimizing the system costs, would meet with strong resistance from industry. We recommend that the users decide which is best for each application based on the particular strengths of the selected technology.

We endorse the ETTM Steering Committee proposal to support both active and backscatter uplink transmission using dual-mode technology readers or tags. This committee's recommendations are significant in that they reflect the concerns of several large regional users (Caltrans, Florida DOT and the E-Z Pass Interagency Group of New Jersey, New York, and Pennsylvania initially and others later).

V. Lane/Position Determination

A number of lane/position determination techniques are being employed by industry. In the MACS application, position information is required in order to assign a Weigh-in-Motion (WIM) reading to the correct vehicle, and in electronic toll collection to bill the correct account and as an aid to identify violators. Since the moving vehicles can scatter RF energy from their lane into neighboring lanes, the measurement technique must handle this out of lane read problem. In some vendor schemes the tag decides which lane it is in by comparing the RF field strengths from the over-the-road reader antennas each focused on one lane. Other schemes compare the RF amplitudes or phases of the uplink signal as collected by the multiple reader antennas to decide the vehicle's location.

We believe that comparing the uplink amplitudes from a backscatter tag or uplink phases for either type tag are the better lane/position determining techniques. Although the market place might be used to demonstrate the best approach it would be difficult to support both reader and the tag based decision schemes in a national standard. Therefore, we recommend that the readers determine the lane/position and that the tags contain no such circuitry.

VII Data Security

CVO have expressed concern about the security of company sensitive data transmitted by the tag. Eavesdropping on the over-the-air communications at a weigh-station or the use of an unauthorized reader are the main threats. Also, the MACS user agencies are concerned about the integrity of safety data carried by the tag; historical as well as weigh-station gathered information. Tampering with the tag's memory and rewriting new data are the main threats here. We have studied the data security threats and vendor strategies for dealing with them. Vendor hardware in the pipe-line would provide only partial data security using the proposed protection schemes. And, the best strategies would not remain secure if published as a national standard.

We believe that better data security solutions could be developed. Additional tag cost would be incurred but the CVO applications better tolerate additional tag costs than in the larger ETC application; the main market for ETTM products. The use of an on-tag micro controller, one of our recommendations, makes practical better data security schemes than would otherwise be possible. The alternative to on-tag safety data is to have access to a national data base which may be more difficult to establish and gain timely access to at each inspection station.

VII Miscellaneous Recommendations

Our earlier report suggest that the MACS application requires the transmission of up to 2 kbits of data from the tag and a digital interface between the tag and on-vehicle microprocessor. The microprocessor module would in turn interface to the vehicle's digital network(s) (e.g. SAE J1939 or SAE J1850) if present, safety sensors, and driver interfaces (display, keypad, etc.) If the tag has adequate memory size (2 kbits) the interface of choice can be much slower than the bit rate. In this case RS 232 is a good choice for the interface if the microprocessor is nearby (to minimize noise pickup in the connecting cable).

If the tag's memory is smaller than the data exchange required for the MACS application (2 kbits), the microprocessor module must include additional memory and the VRC a fast digital interface; perhaps equal to the VRC bit rate. The vehicle's J-Bus will be too slow to keep up with the tag's communication rate. In this case RS 485 would be a good interface choice.

Transferring 2 kbits or more of data from the vehicle while traveling through the reader field-of-view requires a high bit rate to permit multiple reads (for error corrections) and time division multiplexing of the lanes. Vendor hardware bit rates are either low (~10 kbps) or high (250-600 kbps). The high bit rates are all adequate and we somewhat arbitrarily recommend 500 kbps for the standard.

Lastly, certain information can be of value in determining the tag's condition. The tag should be required to sense when its battery is low and transmit this information to the reader or driver so that corrective actions can be taken.

